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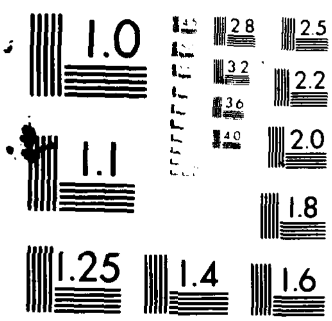


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NAVAL CIVIL ENGINEERING LABORATORY
Port Hueneme, California

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# A PASSIVE SOLAR RETROFIT STUDY FOR CONCRETE BLOCK BUILDINGS

January 1982



An Investigation Conducted by
Department of Energy
Albuquerque Operations Office
Los Alamos National Laboratory
Albuquerque, New Mexico

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A passive solar retrofit study has been conducted for the Navy at the Los Alamos National Laboratory. The purpose of the study was to determine the energy savings obtainable in concrete block buildings from several passive solar heating and conservation strategies. A procedure involving the use of test cell data and computer simulation was employed to assess the

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merits of six retrofit options. The six strategies selected were chosen on the basis of providing a series of options that will deliver increasing energy savings at the cost of correspondingly increased levels of commitment.

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# A PASSIVE SOLAR RETROFIT STUDY FOR THE UNITED STATES NAVY

by

William O. Wray, Charles R. Miles*, and Claudia E. Kosiewicz

ABSTRACT

A passive solar retrofit study has been conducted for the United States Navy at the Los Alamos National Laboratory. The purpose of the study was to determine the energy savings obtainable in concrete block buildings from several passive solar heating and conservation strategies. A procedure involving the use of test cell data and computer simulation was employed to assess the merits of six retrofit options. The six strategies selected were chosen on the basis of providing a series of options that will deliver increasing energy savings at the cost of correspondingly increased levels of commitment.

## I. INTRODUCTION

Many US Navy office buildings and living quarters are constructed with concrete block walls and poured concrete floor slabs. The massive nature of these buildings makes them prime candidates for the application of passive solar space heating retrofits because the structures have enough inherent heat capacity to effectively store and utilize large quantities of solar energy. This study was initiated in order to assess the merits of several retrofit strategies and to compare those strategies with the simple addition of insulation to either the inner or outer surface of the block walls. The results obtained are applicable to south-facing block walls or block walls that depart from true south by no more than 30$^{\circ}$ to the east or west. The optimum orientation for passive solar space heating is generally close to true south, but penalties are small (less than 5%) for deviations of up to 30$^{\circ}$. Our results

*US Navy, Civil Engineering Laboratory, Port Hueneme, California 93043 USA.

indicate that employing passive solar strategies on south-facing block walls is preferable to the use of insulation, which, under some conditions, can actually increase the building heat load.

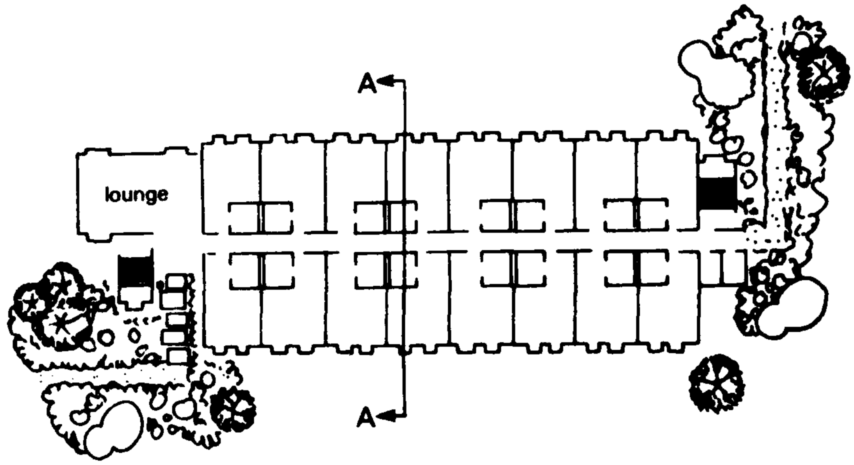
The strategies evaluated in this study are appropriate for new construction as well as for retrofits, although more ambitious designs are possible when passive solar concepts are introduced early in the design process. The best candidates for retrofit are those buildings that have a long axis running within $30^{\circ}$ of an east-west orientation. New buildings should, of course, always be oriented with the long axis in an east-west direction in order to maximize solar gains during the winter on the south wall of the building and minimize solar gains during the summer on the east and west walls.

## II. TYPICAL CONCRETE BLOCK NAVY BUILDING

The floor plan of a typical Navy BEQ (Bachelor Enlisted Quarters) unit of concrete-block construction is presented in Fig. 1. A section of the same building is illustrated in Fig. 2, and Fig. 3 is the floor plan of a typical room. In general, the building may be 2 to 3 stories high and may contain 10 to 20 of these rooms on each floor as well as additional common areas for lounges, concessions, etc., which are usually located at the ends of the building. The external walls are constructed of 8-in. concrete building blocks, and the floors are poured concrete slabs, 6 in. thick on the ground level and 4 in. thick on the upper levels. The interior partitions are generally of lightweight construction, and the windows are single glazed.

The experimental and computational phases of the analysis presented in this report are based on the behavior of a single south-facing zone (Fig. 3) that is thermally coupled to other zones in the structure. The building thermal factor is approximately 12.8 Btu per heating degree day ($^{\circ}$F) per ft$^2$ of floorspace (Btu/DD ft$^2$). Thus, a single 390 ft$^2$ zone experiences a heat load of 4990 Btu/DD.

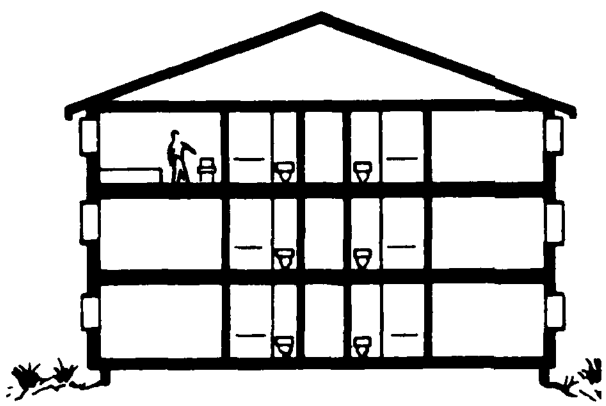
The exterior wall area of the zone (assumed to be south facing) is 124 ft$^2$ of which windows take about 24 ft$^2$. This entire south-facing surface can be considered a solar collector that may be efficient or inefficient, depending on the treatment of the wall.




PLAN OF TYPICAL UNIT, 1st FLOOR (2nd & 3rd SIMILAR)

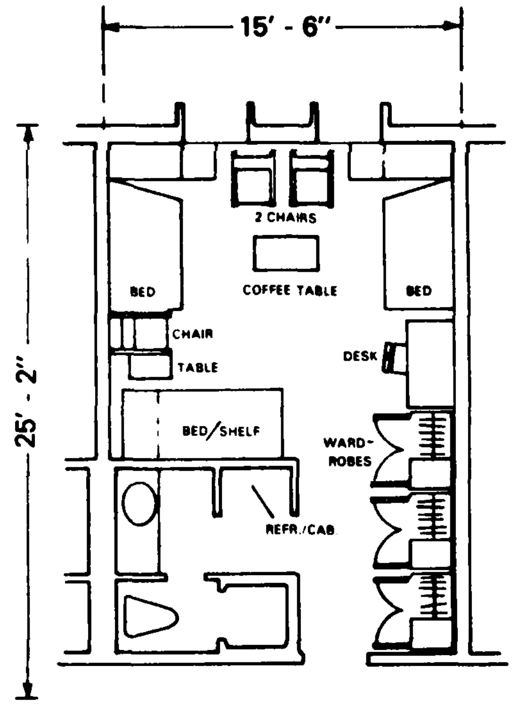
GROSS AREA 22,326 s.f.

Fig. 1.
Floor plan of typical BEQ unit.



SECTION A-A

Fig. 2.
Section of typical BEQ unit.




NET LIVING AREA = 270 $ft^2$

GROSS AREA = 390 $ft^2$

Fig. 3.
Floor plan of typical room.

## III. TEST CELL EXPERIMENTS

Two adjacent instrumented passive solar test cells were used to provide a source of data for validating computer models of a typical concrete block building and the various retrofit options considered in this study (see Fig. 4). The cells are about 5 ft wide, 10 ft high, and 8 ft deep. Construction is 2 by 4 stud frame (except for the south wall) with fiber glass batts in the cavities and 1 in. of polystyrene foam insulation on the inside surfaces. Solid concrete blocks were placed on the floor and suspended from the ceiling on a metal rack to represent the concrete floor slabs present in the actual building. A fixed infiltration rate of two air changes per hour was induced by a blower in order to increase the heat load of the cells and simplify the analysis of infiltration heat transfer. Electric light bulbs with a total power of 1 kW were placed in each test cell as a source of auxiliary heat. The light bulbs were thermostatically controlled by the HP 9845 data acquisition system that limited the globe temperatures of the enclosures to a minimum of 75$^{\circ}$F.

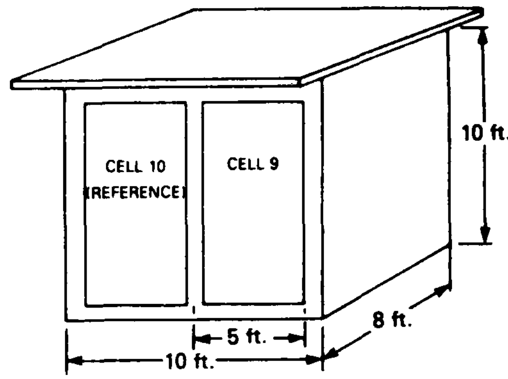



Fig. 4.
Passive solar test cells.

It is important to recognize that the test cells are not intended to be exact simulations of the Navy buildings we seek to analyze. Rather, they are intended to be representative of the concrete block buildings and associated retrofit configurations in the sense that the physical phenomena that dominate the behavior of the prototype buildings also dominate the response of the test cells. The test cells, therefore, provide a source of data that may be used to validate computer simulation models. Having validated the simulation models, one then has the means to predict, simply by making appropriate parameter changes, the behavior of the associated prototype buildings in any climate for which hourly weather data are available.

The south wall of one of the test cells (cell 10) used in this project was constructed to represent a typical Navy concrete block building and was maintained in that fixed reference configuration throughout the test period.

Concrete building blocks with nominal dimensions of 8 in. by 8 in. by 16 in. were set in place and carefully sealed at the edges. One single-glazed 25-in.-wide by 34-in.-high window was centered laterally on the wall with the lower edge about 4 ft above the bottom of the block wall, which was painted beige, a color frequently used on Navy buildings. The measured solar absorptance of the beige blocks was 0.60.

The second test cell (cell 9) was originally configured to be identical to the reference cell, and globe temperatures were monitored to insure that, for all practical purposes, the two cells were thermally equivalent. Then a 12-in.-thick slab of polyurethane was placed on the south wall of each cell and sealed at the edges to allow determination of the building load coefficient (BLC). The BLC is the amount of heat required to maintain a 1-degree temperature difference between inside and ambient temperatures for a period of one day if there are no heat gains or losses through the south wall. For this project the entire south wall, including the block wall and the window, was considered to be a solar collector. The BLCs of the reference and variable configuration cell were found to be

$$BLC_{10} = 597.6 \text{ Btu/DD}$$
$$BLC_{9} = 621.6 \text{ Btu/DD}$$

Having determined the loss characteristics of both test cells, we introduced a series of six retrofits on cell 9. These modifications and the test period for which they were in place are given below:

Cell 9A (Feb. 10-16). The window was double glazed with a 0.5-in. air gap between glazing layers.

Cell 9B (Feb. 18-23). With the double glazing still in place, the exterior surface of the block wall was painted dark brown. The measured solar absorptance of the dark brown blocks was 0.90.

Cell 9C (Feb. 25-Mar. 2). The double-glazed window and dark brown paint were left in place and a 2-in.-thick layer of polystyrene board insulation was bonded and sealed on the inside surface of the block wall. The window was not blocked by the polystyrene.

Cell 9D (Mar. 7-16). The double-glazed window and dark brown paint were left in place. The polystyrene was removed from the inside surface of the block wall, which was converted to an unvented Trombe wall by placing a layer of acrylic Exolite glazing 2 in. from the outer surface. The Exolite was framed around the already double-glazed window. Exolite is a double-walled material with connecting webs that form 0.5-in. square channels.

Cell 9E (Mar. 19-25). The Exolite glazing was removed and the outer surface of the block wall was covered with a 2-in.-thick layer of polystyrene board insulation. The polystyrene was painted beige, and the window, which was not covered, was left in a double-glazed condition.

Cell 9F (Mar. 30-Apr. 13). The polystyrene insulation was removed from the outer surface of the block wall and replaced with a selective absorber manufactured by Berry Solar Products. The Berry foil consisted of chrome oxide (black chrome) deposited on 0.0035-in.-thick copper sheet. Devcon epoxy cement was used to bond the foil to the concrete block surface. The Exolite glazing was then placed over the Berry foil, leaving an air gap of 2 in. to form a selective absorber Trombe wall. The window in the block wall was left double glazed and was not covered by the Exolite.

The use of test cell data for computer model validation is discussed in the next section.

## IV. COMPUTER MODEL VALIDATION

A modified version of SUNSPOT,[1,2] a thermal network code for direct gain buildings, was employed for analysis of the retrofit configurations considered in this study. SUNSPOT is based on PASOLE,[3] an earlier thermal network code developed by R. D. McFarland for thermal storage wall systems. The modified version of SUNSPOT is called SUNMIX in reference to its capability to model the response of passive systems consisting of a mixture of direct gain and thermal storage wall components. The Navy buildings addressed in this paper involve just such a mixture.

In order to test the validity of the SUNMIX code as a model for the buildings considered in this study, calculations were performed for the reference test cell and for each of the six retrofit configurations. The

calculations were driven by hourly weather data recorded on site at the solar laboratory during the appropriate test periods. The calculated results were then compared with data taken directly from the test cells. Close agreement between theory and experiment in all cases indicated that SUNMIX is a valid model for mixed direct gain/thermal storage wall buildings.

Sample plots of the results of these validation exercises are presented in Figs. 5, 6, and 7 for the reference configuration. The measured ambient temperature and measured and calculated values of the temperature on the inside surface of the block wall are presented in Fig. 5. Measured and calculated values of the globe temperature and the auxiliary heating power are given in Figs. 6 and 7. In general, SUNMIX matches test cell data very well. Block-wall temperatures are especially well predicted. Note that although peak auxiliary heating power tends to be slightly underpredicted by the computer model, the total integrated value is very close to that measured in the test cell. Similar results were obtained for all six retrofit configurations.

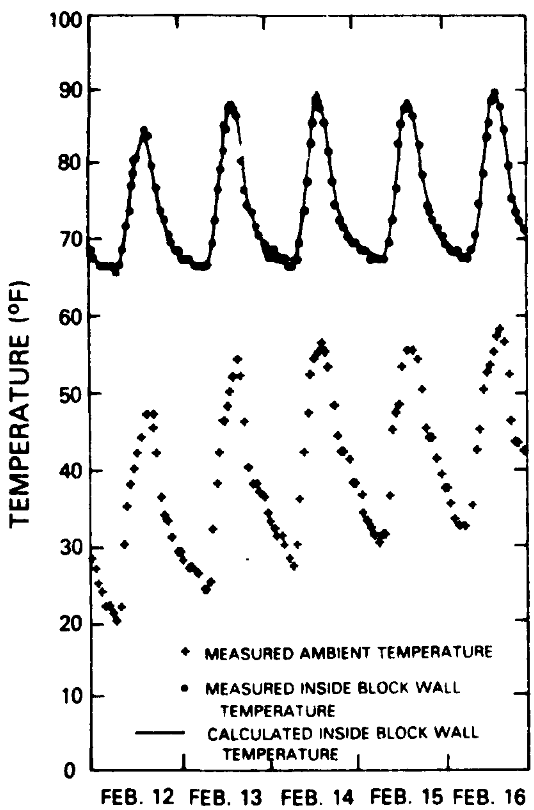



Fig. 5.
Ambient and inside block wall temperatures
for reference test cell.

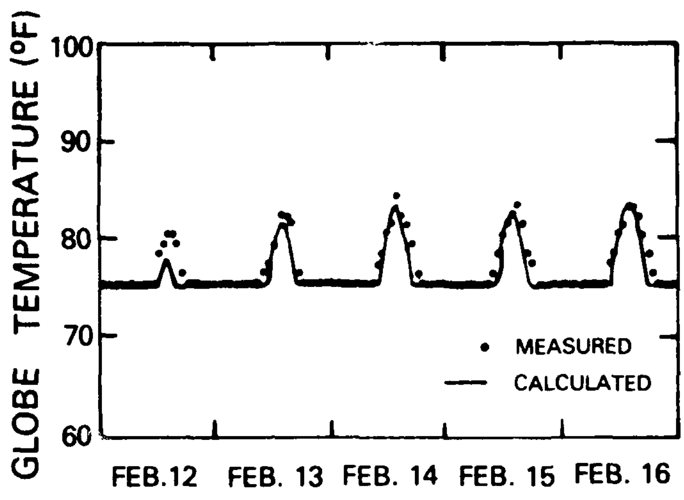



Fig. 6.
Measured and calculated globe temperatures
for reference test cell.

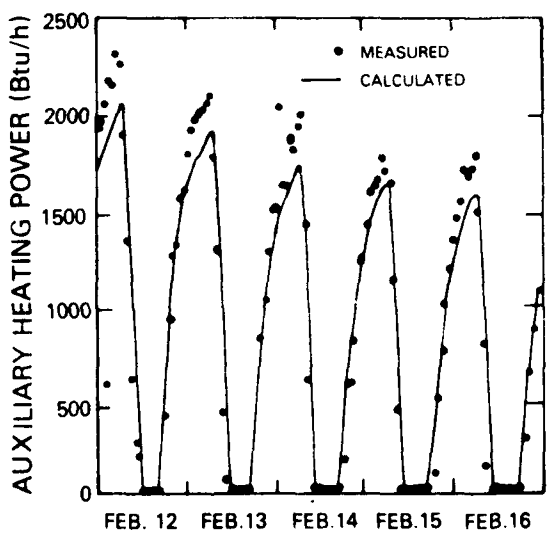



Fig. 7.
Measured and calculated auxiliary heating power
for reference test cell.

## V. SIMULATION ANALYSIS AND RESULTS

### A. Climate Characterization

Having validated the SUNMIX computer model for the typical Navy concrete block building and the six retrofit options, a series of annual performance calculations was performed for building sites in 11 cities in the continental United States. Ten of these cities were selected because large Navy bases are located either within the city limits or nearby. The eleventh city, Los Alamos, was included because it was the site of the test cell experiments and because it has long been considered an ideal climate for passive solar heating. We felt it would be interesting to see how the performance of passive solar systems located at major Navy bases compared with that attainable in a highly favorable climate. Hour-by-hour Typical Meteorological Year (TMY)[4] weather data were used to drive the calculations for the ten Navy cities, and Los Alamos National Laboratory data recorded during 1978 were used for Los Alamos.

In order to provide a basis for organizing the results of the very large data base generated by SUNMIX performance calculations, we have attempted to rank the 11 chosen cities according to their potential for exhibiting large relative solar savings fractions (RSSFs). The RSSF is defined as the amount of energy saved annually by a particular retrofit (relative to the original building) divided by the amount of energy required to heat the original building for 1 year. In earlier studies, we found that the RSSF correlated reasonably well with the ratio of $Q_v$ to DD, where $Q_v$ is the total insulation on a vertical south-facing surface during January, and DD is the 65°F base heating degree days for the same period. In the present study, we have learned that the correlation between RSSF and the weather parameter is greatly improved by taking the $Q_v$-to-DD ratio over a period that includes all months having at least 50 degree days. This new parameter is referred to symbolically as $(Q_v/DD)_T$ where the subscript T stands for total. Table I lists the 11 cities considered in this study and gives the $(Q_v/DD)_T$ ratio of each.

TABLE I

CHARACTERIZATION OF CLIMATE
IN THE 11 CITIES CONSIDERED IN THIS STUDY

| No. | City | $(Q_V/DD)_T$ (Btu/ft$^2$ DD) | Type of Winter Climate |
|---|---|---|---|
| 1. | San Diego, California | 198 | Mild |
| 2. | Los Angeles, California | 185 | |
| 3. | San Francisco, California | 139 | Moderate |
| 4. | Jacksonville, Florida | 129 | |
| 5. | New Orleans, Louisiana | 108 | |
| 6. | Charleston, South Carolina | 100 | |
| 7. | Norfolk, Virginia | 73 | Severe |
| 8. | Los Alamos, New Mexico | 63 | |
| 9. | Seattle, Washington | 60 | |
| 10. | Boston, Massachusetts | 42 | |
| 11. | Chicago, Illinois | 42 | |

The cities in Table I have been grouped into categories labeled mild, moderate, and severe. In a climate considered to be mild, the ratio of $Q_V$ to DD is large, indicating that plenty of sunshine is available to meet the relatively small building heat loads experienced at these locations, and one might expect to achieve large RSSFs without much difficulty. In general, we consider a city with a $(Q_V/DD)_T$ ratio greater than 165 to have a mild winter climate. At the other extreme are the severe winter climates with $(Q_V/DD)_T$ ratios of less than 85, where the amount of sunshine is small compared to the magnitude of the building heat loads likely to occur. In these climates, it will prove difficult to meet a large fraction of the building heat load with passive solar strategies. In the middle we have cities with moderate winter climates for which $(Q_V/DD)_T$ may range from 85 to 165.

Before moving on to the next section, two points must be clarified regarding the information presented in Table I. First, the weather parameter $(Q_V/DD)_T$ provides only a rough indication of the passive solar potential of a given climate. It cannot be used to predict the RSSFs obtainable, but rather is intended to indicate the range of performance one might expect. Second, use of the terms mild, moderate, and severe to characterize the three climate types seems unavoidable, but such usage may be misleading. As a general rule, the highest solar savings fractions will occur in the mild climates, and the lowest solar savings fractions will be observed in the

severe climates. However, the energy saved (heating energy required by original building minus heating energy required by retrofit building) is usually greatest in the severe climates because the heat loads being partially met by solar gains are largest in these cities. This point will be demonstrated in the following section.

B. Retrofit Performance in Three Representative Cities

On the basis of Table I, we have selected San Diego, Jacksonville, and Boston as representative cities with mild, moderate, and severe winter climates. The RSSF of each of the six retrofit designs is plotted in Fig. 8 for each of the three representative cities. The RSSF is defined as the energy

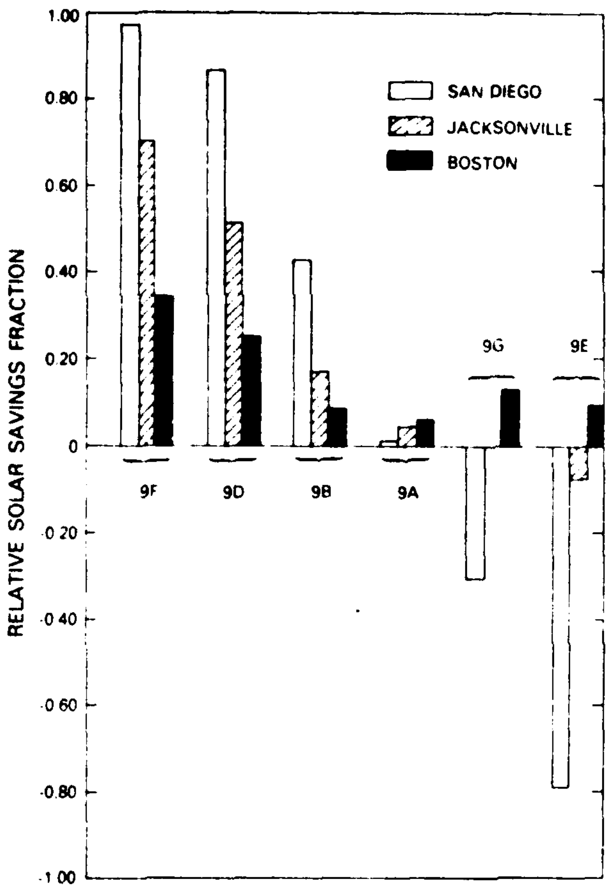



Fig. 8.
Relative solar savings fraction of six retrofit designs in three representative cities.

saved by a particular retrofit configuration relative to the original unmodified Navy design. Thus, if $QAUX_{10}$ represents the auxiliary heat required by the original building and $QAUX_N$ is the heat required by the Nth retrofit, then the RSSF of the Nth retrofit is

$$RSSF = \frac{QAUX_{10} - QAUX_N}{QAUX_{10}}$$

The symbols 9A, 9B, 9D, 9E, and 9F represent retrofit designs that correspond to the test cell configurations that were tested during the winter of 1981 at Los Alamos. Retrofit design 9G is the same as test cell 9C, except that the outer block wall color was changed from dark brown to beige so that the effect of insulation on the interior surface of the block wall could be isolated. These retrofit configurations are summarized in Table II.

TABLE II

RETROFIT CONFIGURATIONS

| Retrofit Label | Configuration |
|---|---|
| 9A | Double glazed window |
| 9B | Double glazed window<br>Dark brown paint on block wall |
| 9D | Double glazed window<br>Dark brown paint on block wall<br>Exolite glazing over block wall |
| 9E | Double glazed window<br>Insulation on outside surface of block wall |
| 9F | Double glazed window<br>Selective absorber on block wall<br>Exolite glazing over block wall |
| 9G | Double glazed window<br>Insulation on inside surface of block wall |

Note first from Fig. 8 that retrofit 9A, for which the windows on the south wall were double glazed, yields small energy savings that, as one would expect, increase with the severity of the climate. The observed energy savings are not large because the window area for the Navy buildings is small, totaling only about 6% of the gross floor area.

Next consider retrofit 9B, which is identical to 9A except that the block wall has been painted dark brown, yielding a solar absorptance of 0.90 compared to 0.60 for the original beige wall. Only a modest gain is realized in the cold, cloudy Boston climate, but the improvement in both Jacksonville and San Diego is quite significant. Since dark brown paint costs no more than beige paint, the incremental cost of retrofit 9B compared to 9A is zero, making 9B very attractive on the basis of economics as well as performance.

Retrofit 9D is obtained by adding double-walled Exolite glazing to configuration 9B. A 2-in. air gap was allowed between the block wall and the inner surface of the Exolite. This retrofit improved performance dramatically in all three cities, but, unlike the previous case, the incremental cost will be significant.

Finally, the best performance is achieved in retrofit 9F for which the dark brown paint of 9D was replaced by Berry foil, a selective absorber. Performance is moderately improved in all three cities.

Let us return now to retrofit 9A, the configuration with double-glazed windows, and introduce conservation features rather than passive solar features. Retrofit 9G is identical to 9A except that 2 in. of polystyrene board insulation has been placed on the inner surface of the block wall. The results are (a) 30% more auxiliary heat than required by the reference design is needed in San Diego, (b) performance is slightly degraded in Jacksonville, and (c) energy savings are increased slightly in Boston relative to 9A. These results indicate that insulating the inner surface of south-facing block walls is detrimental in warm, sunny climates and is of little value in colder, cloudy climates. The passive solar options exhibit much greater potential for energy savings.

Now for one final experiment, we take the insulation from the inside surface of the block wall in retrofit 9G and place it on the outside surface to obtain retrofit 9E. The board insulation is painted the same beige color as the exterior of the block wall that is now covered. Note from Fig. 3 that introduction of this modification would be a serious error. In San Diego the RSSF has dropped to a negative 79%, indicating that we will now have to provide 79% more heat than was required by the original unmodified Navy building. In Jacksonville the RSSF has dropped to -7.6%, and in Boston the energy savings is slightly reduced from that observed for configuration 9G, which had

insulation on the inner surface of the block wall. The general rule is that insulation should never be placed on the outside surface of south-facing block walls. In mild climates, any insulation on the south wall is detrimental to performance, and in moderate to severe climates, insulation on the inside surface yields small energy savings that exceed those obtainable by insulating the outside surface. Insulation on the outer surface of south-facing mass walls negates solar gains that might otherwise occur, and the penalty for negating those gains is severe in warm, sunny climates and small in cold, cloudy climates.

In order to gain a different perspective, the results presented in Fig. 8 were replotted in Fig. 9. Figure 9 is identical to Fig. 8, except that the auxiliary heat savings is plotted on the ordinate rather than the savings fraction. The auxiliary heat savings is the amount of annual space heating energy saved by a given retrofit when applied to the south-facing side of a three-story building having 16 zones per floor (see Figs. 1 and 2). It is assumed that the long side of the building faces south so that 3 x 8 = 24 zones receive solar gains on the exterior wall. It is evident from this figure that the cities with severe climates actually offer the best opportunities for saving energy. Although, as discussed earlier, the RSSFs tend to be small in severe climates, the actual energy savings is large because of the magnitude of the heat load.

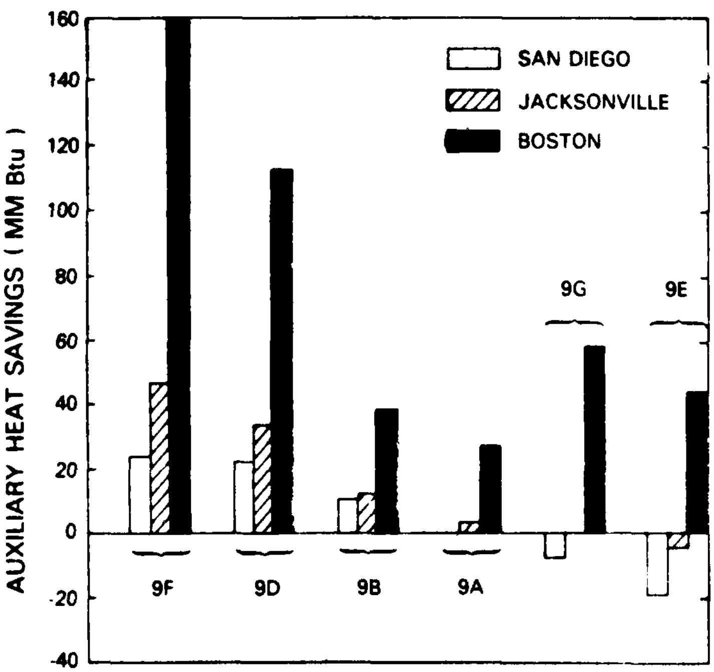



Fig. 9.
Auxiliary heat savings of six retrofit designs in three representative cities.

In Appendix A, bar graphs similar to those in Figs. 8 and 9 are presented for all 11 cities considered in this study. All cities with a given climate type (mild, moderate, or severe) are presented together so that one can judge the significance of the groupings represented in Table I and take note of the exceptional cases that arise. In general, cities with $(Q_V/DD)_T$ ratios in the same group do tend to have comparable relative solar savings fractions for the passive solar retrofits (9A, 9B, 9D, and 9F) but exhibit significant differences for the conservation retrofits (9G and 9E). Inspection of Figs. A-4 through A-6 shows that the auxiliary heat savings does not group well on the basis of $(Q_V/DD)_T$.

In Figs. 10, 11, and 12, the RSSF for retrofit 9D is plotted as a function of the load collector ratio (LCR) for building sites in San Diego, Jacksonville, and Boston. The LCR is defined as the BLC divided by the solar collection area. The BLC is not a function of the heat loss characteristics of the solar collector area and, therefore, does not depend on what retrofit, if any, has been applied to the south-facing wall. Since for a given retrofit we are holding the solar collection area constant at 124 $ft^2$ per zone in the BEQ, the only way to vary the LCR is by varying the infiltration level, the treatment of non-south windows, or the amount of insulation on the non-south walls, the floor, or the ceiling such that the magnitude of the BLC is altered. The BLC for a single zone in the typical Navy building considered in this report is 3244 Btu/DD. Dividing the BLC by the collection area of 124 $ft^2$ yields the reference value of the LCR,

$$LCR_{Ref} = \frac{3244}{124} = 26.16 \text{ (Btu/DD ft}^2\text{)} \quad .$$

Inspection of Figs. 10-12 shows that relative solar savings fractions of 0.86, 0.51, and 0.25 can be achieved by retrofit 9D in San Diego, Jacksonville, and Boston at the reference LCR. However, the RSSF can be increased in all three cities by better insulating the non-south walls, thereby reducing the magnitude of the LCR. Thus Figs. 10-12 can be used to determine the combined effect of applying conservation measures (insulation and caulking) to buildings that have also received a passive solar retrofit. In Appendix B, similar plots are presented for retrofit options 9B, 9D, and 9F in each of the three cities chosen to represent mild, moderate, and severe climates.

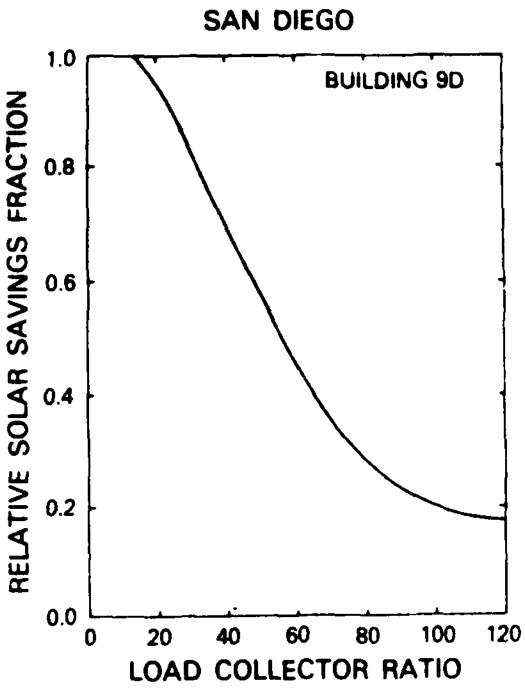



Fig. 10.
Relative solar savings fraction vs load collector ratio for retrofit 9D in San Diego.

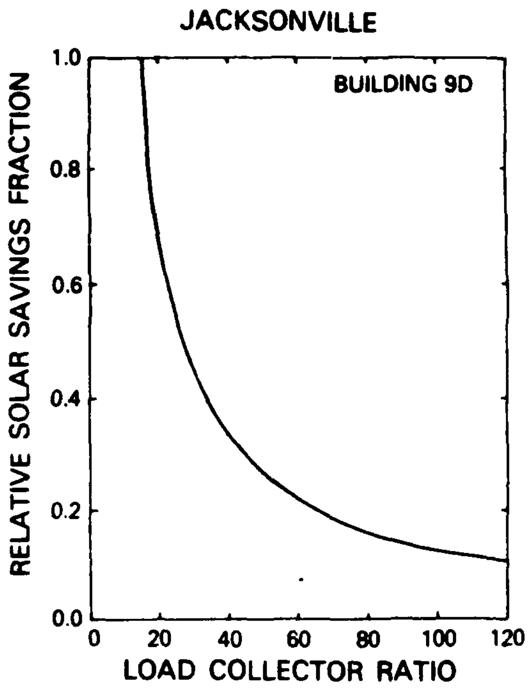



Fig. 11.
Relative solar savings fraction vs load collector ratio for retrofit 9D in Jacksonville.

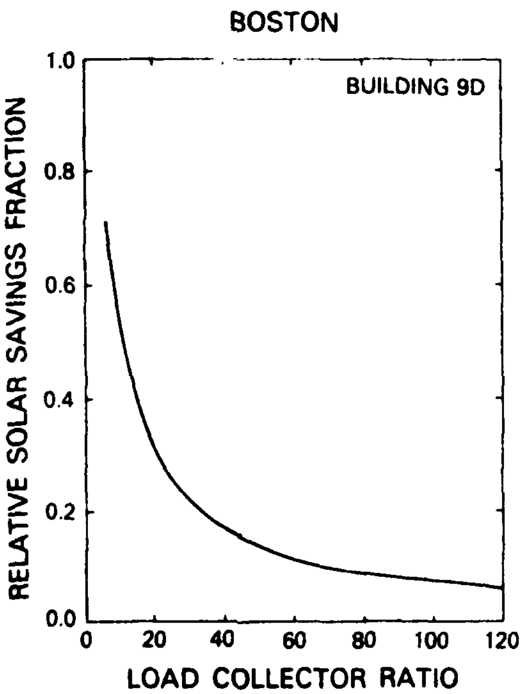



Fig. 12.
Relative solar savings fraction vs load collector ratio for retrofit 9D in Boston.

## VI. SUMMARY

The performance of six retrofit options for concrete block buildings has been investigated in Los Alamos, New Mexico, and ten additional cities that are sites of major Navy bases. The cities were placed in groups based on the ratio of solar radiation to heating degree days observed at each location. A mild climate group (San Diego and Los Angeles), with large solar-to-degree day ratios, and a severe climate group (Norfolk, Los Alamos, Seattle, Boston, and Chicago), with small solar-to-degree day ratios, were identified. Cities with intermediate solar-to-degree day ratios were placed in a moderate climate group (San Francisco, Jacksonville, New Orleans, Charleston). It was determined that the fractional heating energy saved by the various retrofits relative to the original building depended largely on climate group. Thus it was possible to characterize the performance potential of each retrofit by studying its behavior in three cities representative of the three climate groups. San Diego, Jacksonville, and Boston were selected as being most representative of the mild, moderate, and severe groups, respectively.

Double glazing the windows in concrete block buildings yielded small relative solar savings fractions (RSSFs) of about 10% or less, depending on the severity of the climate. The savings fractions obtained were largest in the severe climate of Boston and smallest in the mild San Diego climate. The small window area of the typical Navy building (6% of floorspace) explains the low RSSFs associated with double glazing.

Changing the color of the south-facing block wall from beige (solar absorptance = 0.6) to dark brown (solar absorptance = 0.9) resulted in RSSFs of about 10% in Boston, 20% in Jacksonville, and 40% in San Diego. Applying double-walled exolite glazing over the dark brown surface increased these savings to 25% in Boston, 50% in Jacksonville, and 85% in San Diego. Finally, by covering the concrete block surface beneath the exolite glazing with Berry foil, a selective absorber, RSSFs of 55%, 70%, and 95% were obtained in the severe, moderate, and mild climates.

Placing insulation on the inside surface of south-facing block walls caused a negative RSSF of 30% in San Diego, yielded no benefit in Jacksonville, and gave positive savings of 15% in Boston. Moving the insulation to the outside surface of the block wall reduced the savings fraction in all three locations.

It is very important to note that although passive solar retrofits produce smaller savings fractions in the severe climates, the absolute energy savings are greatest in those locations. Large energy savings are realized in severe climates because the building heat loads that are being partially met by solar gains are large. Thus, the cost effectiveness of the passive solar retrofits considered in this study is greatest in the locations with small solar-radiation-to-heating-degree day ratios.

## REFERENCES


1. W. O. Wray and J. D. Balcomb, "Sensitivity of Direct Gain Space Heating Performance to Fundamental Parameter Variations," Solar Energy 23, No. 5, 1979, pp. 421-426.

2. W. O. Wray, N. M. Schnurr, and J. E. Moore, "Sensitivity of Direct Gain Performance to Detailed Characteristics of the Living Space," Proceedings of the Fifth National Passive Solar Conference, Amherst, Massachusetts, Oct. 19-26, 1980, Vol. 5.1, pp 92-95.

3. R. D. McFarland, "PASOLE: A General Simulation Program for Passive Solar Energy," Los Alamos National Laboratory Informal Report, LA-7433-MS, 1978.

4. SOLMET, Volume I: User's Manual, TD-9724, prepared by the National Climate Center, Ashville, North Carolina, for the Department of Energy.



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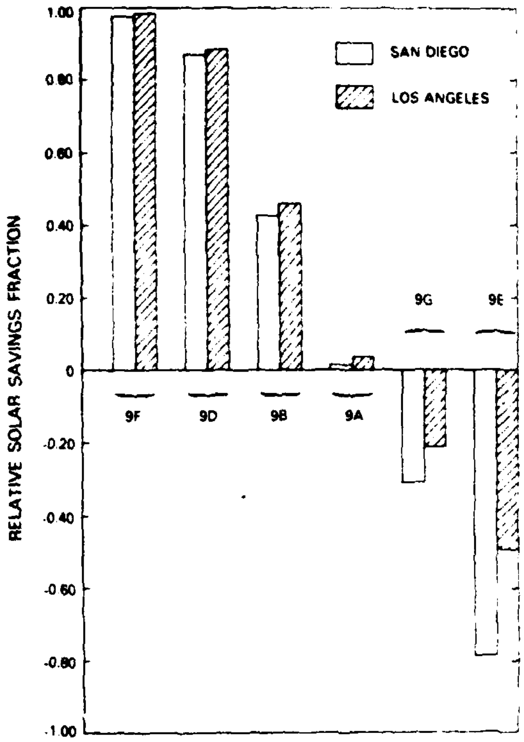


Fig. A-1.
Relative solar savings fraction of six retrofit designs in cities with mild winter climates.

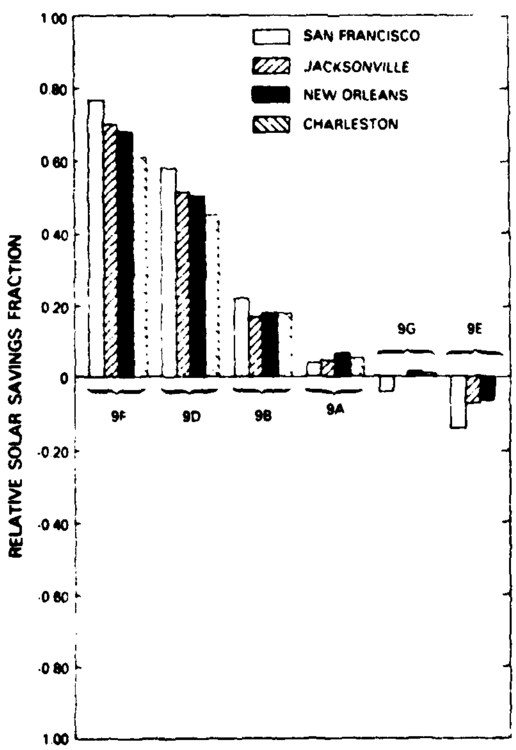


Fig. A-2.
Relative solar savings fraction of six retrofit designs in cities with moderate winter climates.

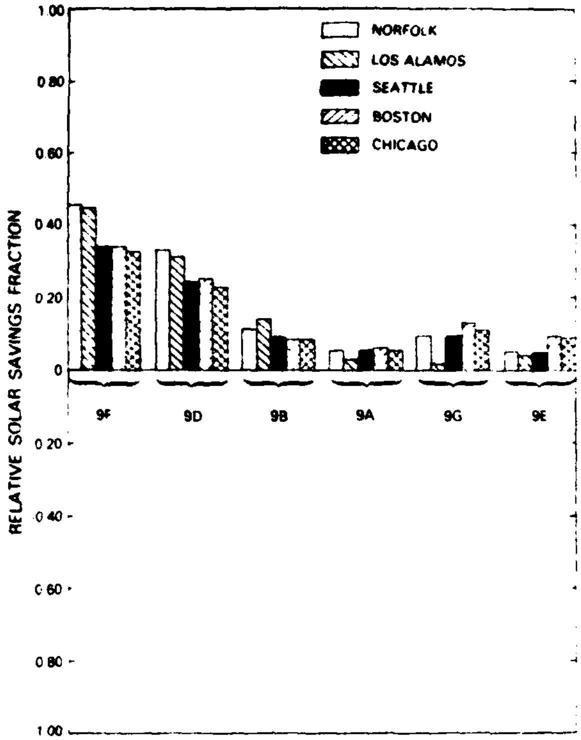


Fig. A-3.
Relative solar savings fraction of six retrofit designs in cities with severe winter climates.

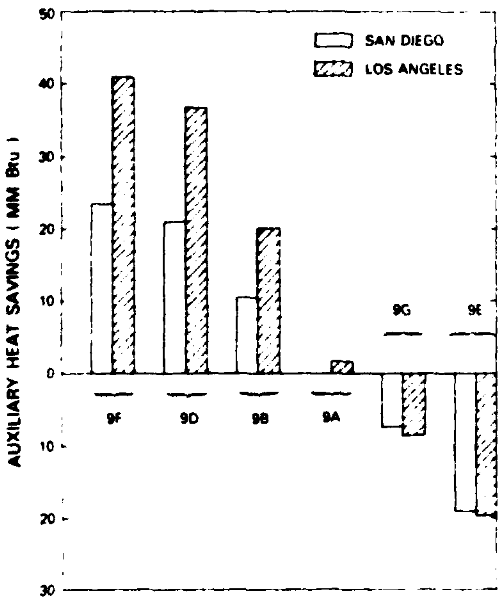


Fig. A-4.
Auxiliary heat savings of six retrofit designs in cities with mild winter climates.

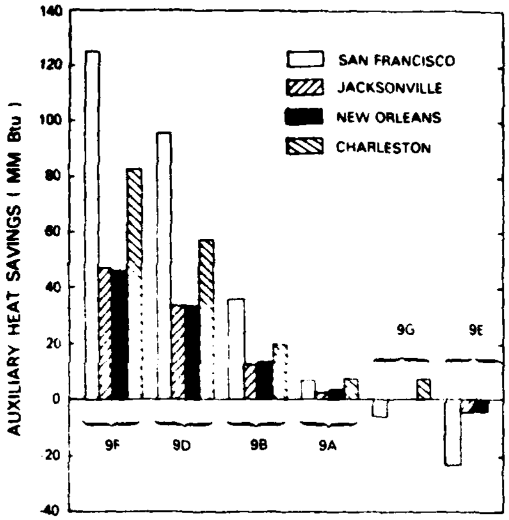


Fig. A-5.
Auxiliary heat savings for six retrofit designs in cities with moderate winter climates.

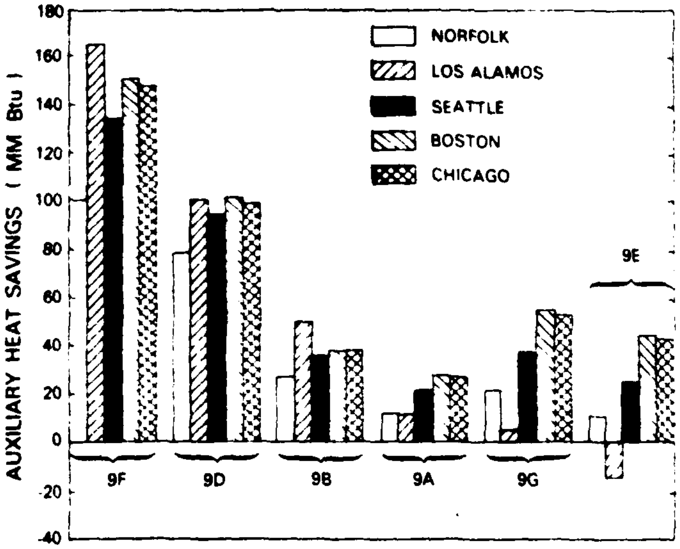


Fig. A-6.
Auxiliary heat savings for six retrofit designs in cities with severe winter climates.

APPENDIX B

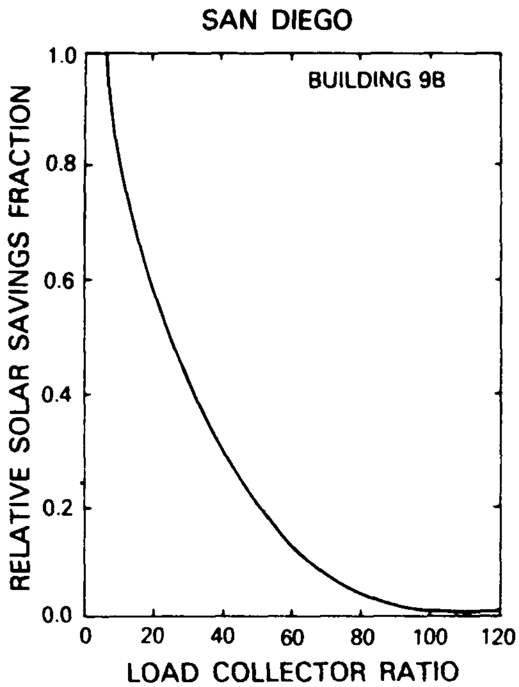


Fig. B-1.
Relative solar savings fraction vs load collector ratio for retrofit 9B in San Diego.

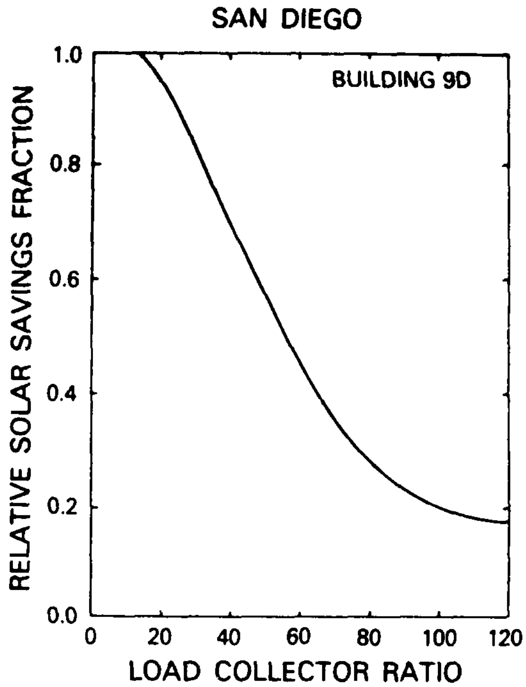


Fig. B-2.
Relative solar savings fraction vs load collector ratio for retrofit 9D in San Diego.

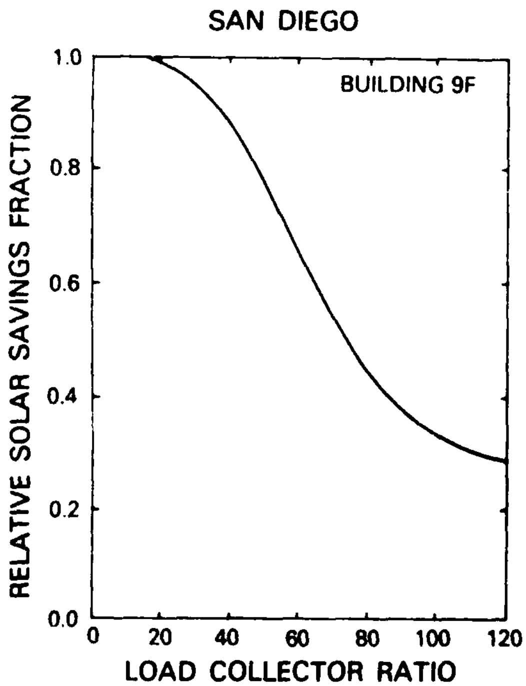


Fig. B-3.
Relative solar savings fraction vs load collector ratio for retrofit 9F in San Diego.

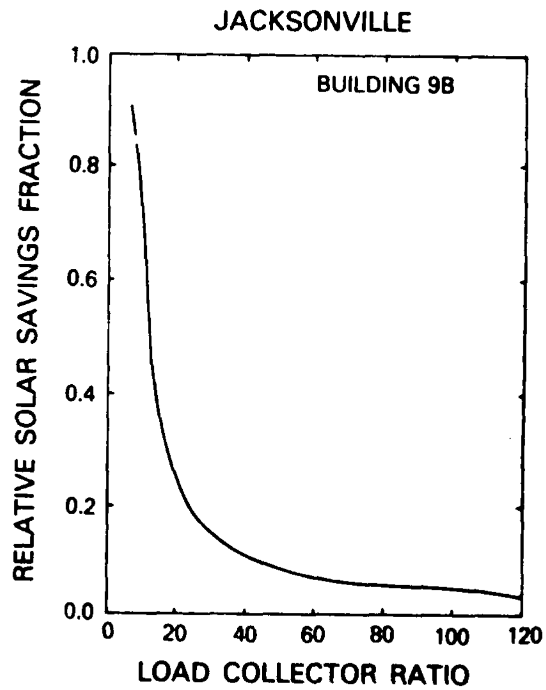


Fig. B-4.
Relative solar savings fraction vs load collector ratio for retrofit 9B in Jacksonville.

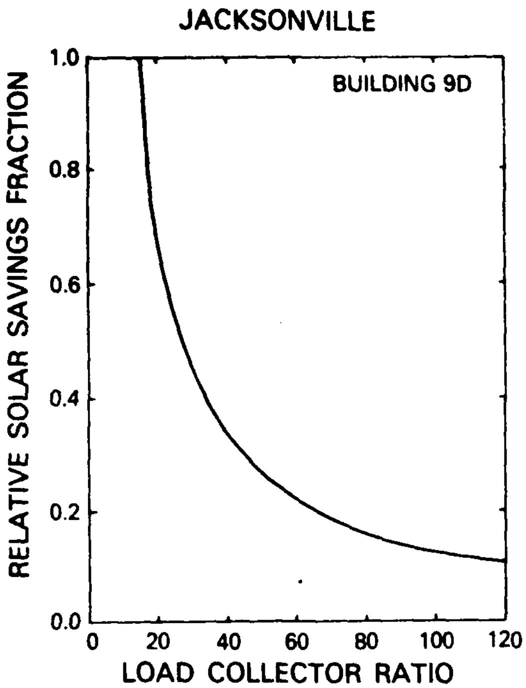


Fig. B-5.
Relative solar savings fraction vs load collector ratio for retrofit 9D in Jacksonville.

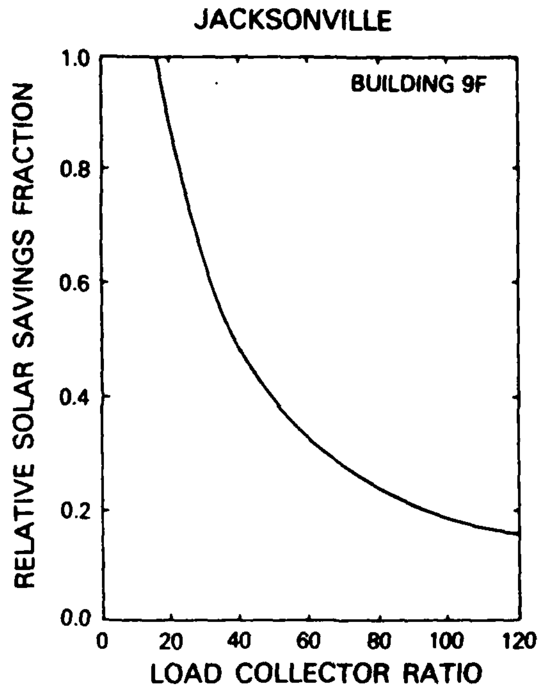


Fig. B-6.
Relative solar savings fraction vs load collector ratio for retrofit 9F in Jacksonville.

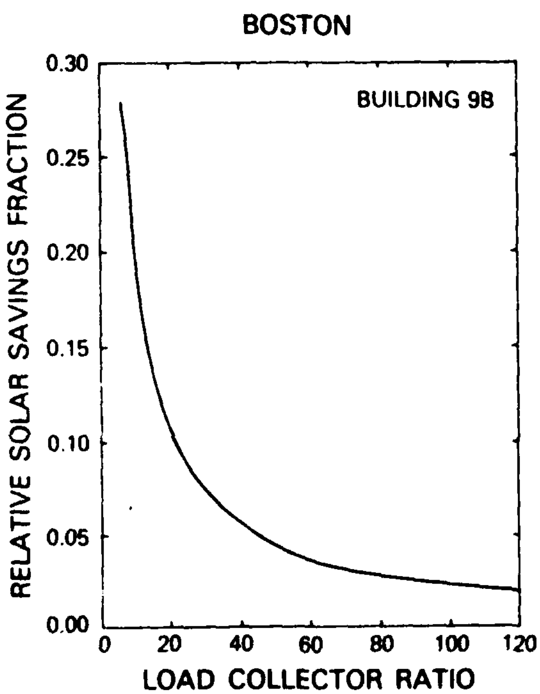


Fig. B-7.
Relative solar savings fraction vs load collector ratio for retrofit 9B in Boston.

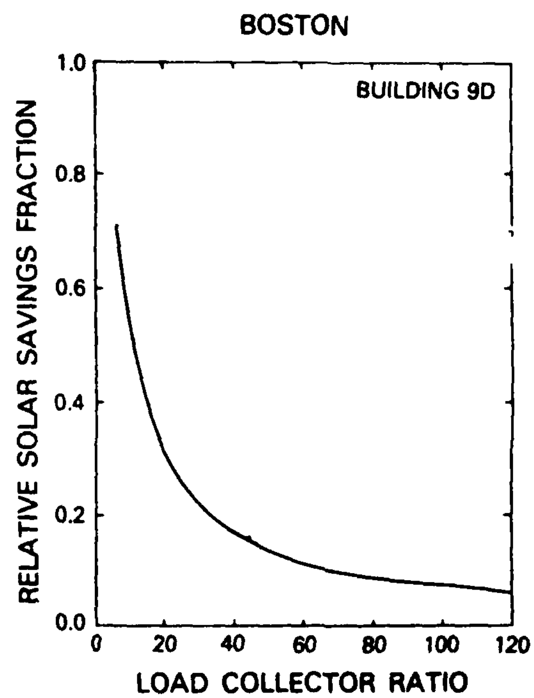


Fig. B-8.
Relative solar savings fraction vs load collector ratio for retrofit 9D in Boston.

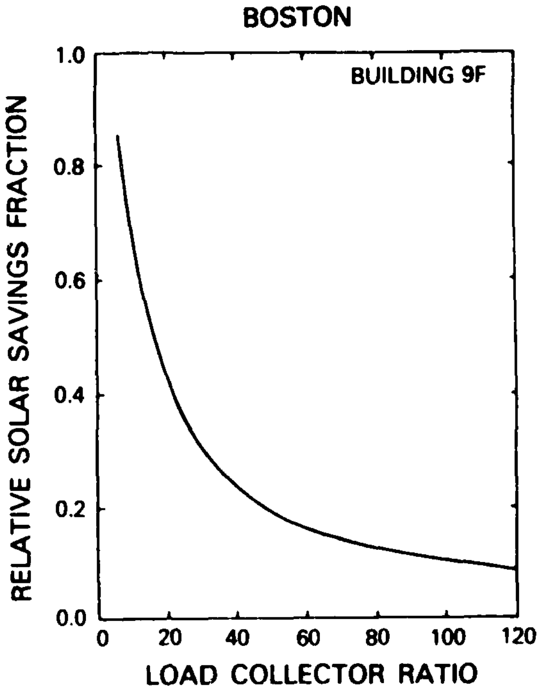


Fig. B-9.
Relative solar savings fraction vs load collector ratio for retrofit 9F in Boston.

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